Evaluation of the adaptation of groundwater quality in the Ketama Al-Hoceima region (Morocco) to agricultural irrigation

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Abstract. In the Ketama region, irrigation used to depend on rainwater and surface water. However, with drought and water shortages affecting the region, farmers are increasingly relying on groundwater. "Recognizing the critical importance of water quality in irrigation, a total of 164 water samples were collected from various points and subjected to physicochemical analysis. The assessment of groundwater suitability for irrigation encompassed several parameters, including chloride, electrical conductivity (EC), percentage of soluble sodium (% Na), sodium adsorption ratio (SAR), residual sodium carbonate (RCS), magnesium adsorption ratio (MAR), permeability index (PI), Kelley ratio (KR), potential salinity (PS), synthetic harmfulness coefficient (K), irrigation coefficient (Ka), chloro-alkaline indices (CAI-1 and CAI-2), and irrigation water quality index (IWQI).". Results showed that 43.29% (EC), 82% (Na), 68.40% (SAR), and 68.29% (Ka) of groundwater samples were excellent and that 77% (PI) of samples were suitable for irrigation. The IWQI revealed that 21.96% of samples are considered to have high restrictions. This study aims to provide crucial information on irrigation water quality in the region, providing valuable data for various stakeholders to make informed decisions on agricultural practices and the sustainable use of water resources, particularly in the face of challenges posed by climate change and water shortages.
Keywords: Groundwater, Water quality, Irrigation, Ketama, Al-Hoceima region

1 Introduction

Severe water shortages plague the majority of nations worldwide, particularly in arid and semi-arid areas [1]. These regions are known for their erratic rainfall patterns, frequent overuse of groundwater, and high evaporation, which cause the volume of groundwater to significantly decline [2]. The security of water supply for agricultural irrigation relies heavily on groundwater resources [3]. The Ketama region, in particular, relies heavily on groundwater for its agricultural irrigation activities. The mineral content of irrigation water, which indicates its quality, is a key factor in how it affects the soil and plants. High salt concentrations in irrigation water can compromise agricultural productivity [3,4].
To maximize agricultural productivity in the research region, it is crucial to assessement the quality of agricultural irrigation water. Groundwater quality of in the Ketama region was assessed using several indices to assess agricultural irrigation's suitability [3,5].

2 Study area

The study area lies between 35°0'0" to 34°40'0"N and 4°20′0" to 4°50′0"W. The total area covered by this zone is 956 km^2. The study region experiences alternating dry and wet seasons because of its climate typically semi-arid. The average yearly precipitation is less than 400 mm, and the average monthly T°C is from 13 to 24 °C [6].

The study area comprises 9 rural communes such as Taghzout, Bni Bouchibet, Abdelghaya Souahel, Issaguen, Moulay Ahmed Cherif, Tlat Ketama, Tamsaout, Bni Bounsar and Bni Ahmed Imougzen (Figure 1).

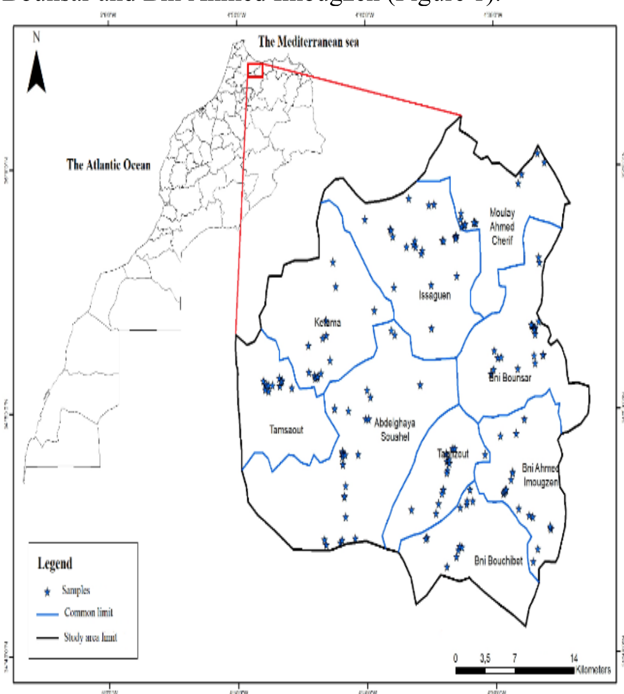

Fig. 1. Study area with spatial distribution of groundwater samples.

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2.1 Geology

The Ketama unit forms the bulk of the sub-Aboriginal intrarifane area in its eastern part. It includes, above the Liassic and Upper Jurassic flysch, a bar of tithonic calcareous mainly pelagic, with intraformational conglomerates, followed by a thick and varied neoconiianc. The Ketama unit is essentially of the Lower Cretaceous. Its albo-aptian sandstone flysch forms the high ridges of J. Tidirhine (2452 m, highest point of the Rif) [7].

3 Materials and methods

164 groundwater samples in all were gathered in 9 rural communes during 2021. Groundwater was collected in double-rinsed 1.5 L polyethylene bottles. Pumping was continued for a sufficiently long duration to remove accumulated water and ensure representative data. Following sampling, groundwater samples were identified, stored at 4°C in isothermal crates fitted with cold accumulators, afterward, it is conveyed to the laboratory for analysis. The sampling points' coordinates were established utilizing specialized Global Positioning System (GPS) equipment (GARMIN GPSmap 62s). Physicochemical analyzes were performed according to the method described by Jean Rodier (2009) [8].

Table 1. Methods used for groundwater physico-chemical analyses.

Parameters	Analysis method (equipment)
pH	InoLab pH 7111
Electrical Conductivity (EC, µS/cm) Total Dissolved Solids (TDS, mg/l)	Hanna HI98311
Sodium (Na^+, mg/l), Potassium (K^+, mg/l)	Flame photometer (type: ELICO CL378)
Sulfate (SO_4^{2-}, mg/l) Nitrate (NO_3^-, mg/l)	UV spectrophotometer (type: RYLEIGH UV-9200)
Calcium (Ca^{2+}, mg/l) Magnesium (Mg^{2+}, mg/l)	Volumetric dosing with EDTA
Bicarbonate (HCO_3^-, mg/l)	Volumetric dosing with **HCl**
Chloride (Cl^-, mg/l)	Volumetric dosing with **$AgNO_3$**

4 Results and discussion

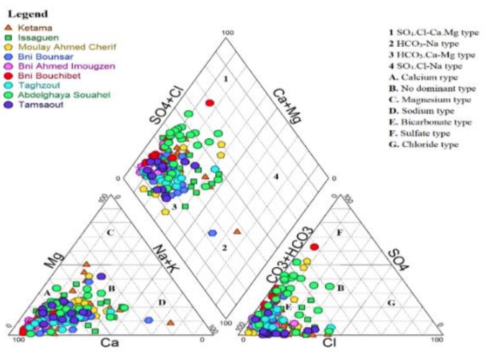

Fig. 2. Piper plot of groundwater in the Ketama region.

Analysis of the groundwater geochemical results, presented in the Piper diagram [9] (Figure 2), reveals a marked predominance of the Ca-HCO3 calcium bicarbonate chemical facies, representing 80.34% of the water samples, followed by the Ca and Mg-Cl and SO_4 facies with 17.94% and finally the sodium and potassium carbonate facies with 1.7%.

4.1 Evaluation of water quality for irrigation

Table 2. An outline of the statistical methods employed for evaluating irrigation water quality.

Parameters	unit	Min	Max	Average
pH	-	5.81	8.50	7.33
HCO_3^-	mg/L	12.20	506.30	149.49
SO_4^{2-}	mg/L	0.00	306.20	38.10
TDS	mg/L	30.25	1455.88	307.01
CE	µS/cm	37.30	1580.00	368.35
Cl^-	meq/L	0.09	3.69	0.46
SAR	meq/L	0.07	1.77	0.35
Na	%	3.64	67.13	14.28
RSC	meq/L	-4.36	0.43	-0.89
MAR	%	1.88	49.90	27.47
PI	%	25.64	190.14	63.15
RK	-	0.03	2.00	0.16
K	-	0.54	14.98	4.03
Ka	-	8.59	324.91	83.59
PS	meq/L	0.15	4.97	0.86
CAI-1	-	-4.10	0.84	-0.11
CAI-2	-	-0.15	0.64	0.02

The minimum, maximum, and average values of the many criteria that were utilized to determine whether the groundwater in the Ketama region was suitable for agricultural irrigation are displayed in Table 2.

Groundwater pH area ranged from 5.81 to 8.50, with an average of 7.33. The results show that 12.16% of samples did not comply with Moroccan irrigation regulations (6.5 <pH <8.4) [10], which may affect sensitive crops.

HCO_3^- ranged from 12.20 to 506.30 mg/L with an average of 149.49 mg/L, so all samples comply with Moroccan irrigation regulations (<518 mg/L) [10].

SO_4^{2-} ranged from 0.00 to 306.20 mg/L with an average of 38.10 mg/L, so 1.21% of samples failed to comply with Moroccan irrigation regulations (<250 mg/L) [10].

TDS: Determining the total dissolved solids in irrigation water is crucial to knowing the condition of the contaminants there. For irrigation, water with a TDS below than 7680 mg/l is deemed appropriate [10].

TDS of water varies from 30.25 mg/L to 1455.88 mg/L, with an average of 307.01 mg/L. Consequently, all water points are suited for irrigation.

EC of water used for irrigation is a sign of crop salinity risk. By altering the aeration and permeability of the soil, salts in irrigation water have the potential to directly and indirectly impact plant growth [5].

Ideal groundwater salinity for irrigation is typically considered to be less than 250 µS/cm. Salinity levels ranging between 250 and 750 µS/cm are generally deemed appropriate for irrigation purposes; if it falls between 750 and 2250 µS/cm, it is judged appropriate for agricultural irrigation. Lower crop yields and soil salinization can result from irrigation of agricultural land using groundwater with an EC of more than 2250 µS/cm [13]. 43.29% of the research area's groundwater samples were judged excellent, 48.78% good, and 7.93% acceptable for irrigation.

Cl^-, with high levels in water, are often considered an indicator of pollution and a marker of groundwater contamination [2]. Chloride concentration varies between 0.09 meq/L and 3.69 meq/L, with an average of 0.46 meq/L. All groundwater samples show chloride concentrations below the quality threshold of 4 meq/L for irrigation water [11]. Consequently, the quality of all samples is considered excellent for irrigation.

According to SAR, irrigation water is classified into quality categories based on specific values: SAR < 2, 2 < SAR < 12, 12 < SAR < 22, 22 < SAR < 32, and SAR > 32, corresponding to very low, low, significant, high, and very high quality respectively [12], while SAR is a crucial factor in assessing the risk of soil sodification [13]. For percent water-soluble sodium (%Na) [14], the assessment categories are as follows: %Na ranging from 0 to 20, 20 to 40, 40 to 60, 60 to 80, and %Na exceeding 80, classifying groundwater as excellent, good, allowable, doubtful, and unsuitable for agricultural irrigation, respectively [15].

The following formula is utilized to calculate % Na:

$$\%\,Na = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \text{ x } 100 \quad (1)$$

82% of samples with excellent quality, 17% good quality, and 1% doubtful for irrigation.
The subsequent formula is employed to ascertain the SAR:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad (2)$$

All sample has a SAR value that is extremely low, below 2.

High levels of Residual Sodium Carbonate (RSC) in groundwater samples in comparison to calcium and magnesium can impact soil permeability [16]. A high RSC may indicate that the water has too much carbonate and bicarbonate, which could make it more difficult for the soil to absorb the nutrients and water needed for crop growth. The following formula is used to determine the RSC:

$$RCS = (HCO_3^- + CO_3^{2-}) - (Mg^{2+} + Ca^{2+}) \quad (3)$$

Water deemed appropriate for irrigation has a RSC below 1.25 meq/l [17]. Based on the results, all samples (100%) can be used for irrigation.

When the Magnesium Adsorption Rate (MAR) is greater than 50, it is deemed hazardous, rendering the waters unfit for irrigation and human consumption [18]. Ca^{2+} and Mg^{2+} are essential for restoring degraded plant structure and essential functions. However, the use of groundwater for irrigation has an impact on MAR levels, thereby affecting soil alkalinity and crop productivity.

MAR is calculated using the following formula:

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \text{ x } 100 \quad (4)$$

Groundwater samples from the Ketama region have MAR values below 50, This means that 100% of water samples from the Ketama region are suited for irrigation.

The Permeability Index (PI) serves as a tool for evaluating the appropriateness of irrigation water for irrigation purposes.

This formula is used to calculate PI:

$$PI = \frac{Na^+ + \sqrt{HCO3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \text{ x } 100 \quad (5)$$

77% of the samples in our study had PI values under 75, making them suitable for irrigation, while 23% of the samples had PI values over 75, making them inappropriate for irrigation. Soil water levels of calcium, magnesium, sodium and bicarbonate have an impact on soil quality.

Using the Kelly Ratio (KR), the amount of Na^+ present in groundwater samples was further quantified. Higher values suggest that the water is not appropriate for this application, but water with a KR value below 1 is thought to be suitable for irrigation [14].

KR is calculated using the following formula:

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad (6)$$

KR values (Table 2) showed that 99% of groundwater samples had KR values less than 1, meaning they may be used for irrigation. Only 1% of samples, on the other hand, had KR values more than 1, indicating that they shouldn't be watered.

The amount of sodium and chloride ions present in soil water is depicted in the USSL salinity diagram. It serves as a tool for assessing both soil salinity and the quality of irrigation water.

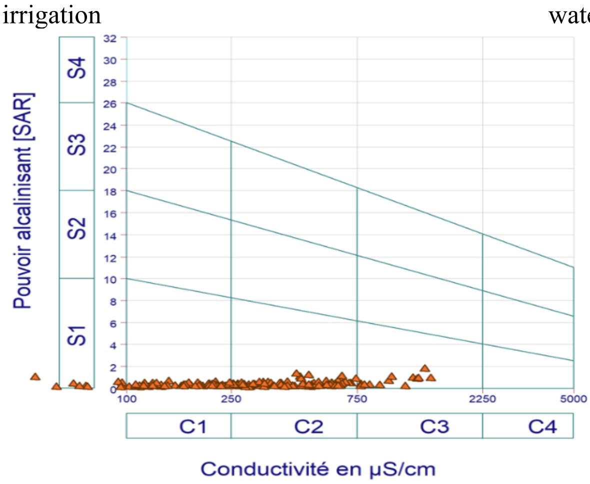

Fig. 3. USSL salinity diagram for SAR and EC classification of irrigation water as defined by Richards (1954) [19].

Groundwater in the Ketama region is classified as good quality (S1C1), moderate risk quality (S1C2), and high-risk quality (S1C3). Class C1 water is suitable for most crops and soils, with a low probability of soil salinization (Figure 3).

Water's synthetic harmfulness coefficient (K) is used to assess the saline and alkaline risk associated with it.

$$K = 12.4M + SAR \quad \textbf{(7)}$$

Where M represents total dissolved matter in grams per liter.

Groundwater is classified according to its synthetic harmfulness coefficient (K) as follows: K < 25 is considered excellent, 25 < K < 36 is classified as good, 36 < K < 44 is considered moderately unsuitable, and K > 44 is considered unsuitable for agricultural irrigation [3]. Groundwater samples from the Ketama region had an average K value of 4.03 with a range of 0.54 to 14.98 (Table 2). As a result, every water sample is rated as being of exceptional quality for use in agricultural irrigation.

The Ka value, also referred to as the Irrigation Coefficient, is determined by assessing the harm inflicted on 40 varieties of crops due to sodium salt, in comparison to the most pronounced damage caused by exposure to an alkaline solution [3,12].

Classifications for groundwater based on Ka value are as follows: Ka > 18 is considered excellent, 6 < Ka < 18 is deemed acceptable, 1.2 < Ka < 6 is moderately inadequate, and Ka < 1.2 is deemed unsuitable for use in agricultural irrigation [12]. Ka is calculated using the following formula :

$$Ka = \begin{cases} \frac{288}{5Cl^-} & \text{if} \quad Na^+ < Cl^- \\ \frac{288}{Na^+ + 4Cl^-} & \text{if} \quad Cl^- < Na^+ < Cl^- + 2SO_4^{2-} \\ \frac{288}{10Na^+ - 5Cl^- - 9SO_4^{2-}} & \text{if} \quad Na^+ > Cl^- + 2SO_4^{2-} \end{cases} \quad \textbf{(8)}$$

The Ka values for groundwater samples obtained from the Ketama region varied between 8.62 and 324.94, averaging at 83.59 (Table 2). As a result, 68.29% of these samples were classified as excellent, while 31.71% were deemed suitable for agricultural irrigation.

Potential salinity (PS) is determined by the following formula:

$$PS = Cl^- + \frac{1}{2} SO_4^{2-} \quad \textbf{(9)}$$

Groundwater is classified according to PS value as follows: PS < 3 is deemed excellent to good, 3 < PS < 5 is considered good to detrimental, and PS > 5 is regarded as detrimental to unsatisfactory for agricultural irrigation [3]. The PS values of groundwater samples from the Ketama region range from 0.15 to 4.97, with an average of 0.86 (Table 2). Consequently, all water samples are classified as excellent quality for irrigation.

In the evaluation of irrigation water, chloro-alkali indices (CAI-1 and CAI-2) are commonly utilized to verify the presence and type of ion exchange in the water. This frequently controls how contaminants and chemicals flow through soil and water. Determining how the composition of groundwater varies as it percolates through the soil is therefore crucial. When Na and K in the water replace Mg and Ca, this constitutes direct ion exchange. On the other hand, an exchange with positive values that is reversed is referred to as indirect [14]. The formula below is used to determine CAI-1.

$$CAI - 1 = \frac{(Cl^- - (Na^+ + K^+))}{Cl^-} \quad \textbf{(10)}$$

CAI-2 is calculated using the following formula:

$$CAI - 2 = \frac{(Cl^- - (Na^+ + K^+))}{(HCO_3^- + SO_4^{2-} + CO_3^{2-} + NO_3^-)} \quad \textbf{(11)}$$

Observations revealed that 50% of the water samples demonstrated positive values for both CAI-1 and CAI-2, whereas the remaining 50% displayed negative chloro-alkaline indices. This observation suggests that both direct and reverse ion exchange processes play important roles in regulating the amount of major ions in groundwater in the Ketama region.

4.2 Irrigation Water Quality Index (IWQI)

The overall quality of groundwater for agricultural use is evaluated using the IWQI [20]. It uses a single number to define irrigation water quality. This helps to avoid complicated data intervals in water quality assessments. The following formula was used to generate the IWQI index utilizing the primary parameters (CE, Na^+, Cl^-, HCO_3^-, and SAR) that are significant in determining the quality of water for agricultural use:

$$IWQI = w_i * \mathbf{q_i} \quad \textbf{(12)}$$

Based on the physicochemical parameter values, the aggregation weights (wi) (Table 3) and the water quality parameter values (qi) (Table 4) were calculated using the criteria established by Ayers and Westcot, as per the following formula:

$$q_i = \left(q_{imax} - \left(\frac{(x_{ij} - x_{inf}) * (q_{iamp})}{x_{amp}}\right)\right) \quad \textbf{(13)}$$

With :

- q_{imax}: The maximum value within the respective class of qi ;
- χ_{ij}: The measured value for each parameter;
- χ_{inf}: The lower limit value of the class to which the observed parameter pertains;
- q_{iamp}: The amplitude of class qi ;
- χ_{amp}: The range or amplitude of the class to which the parameter is assigned.

Groundwater with IWQI < 40, 40 < IWQI < 55, 55 < IWQI < 70, 70 < IWQI < 85, and 85 < IWQI < 100 are classified as severely restricted, highly restricted, moderately restricted, mildly restricted, and unrestricted for agricultural use, respectively [20].

Table 3. Physico-chemical parameters for determining IWQI [20]

Parameters	(w_i)
EC (µS/cm)	0.211
Na^+ (meq/L)	0.204
HCO_3^- (meq/L)	0.202
Cl^- (meq/L)	0.194
SAR	0.189

Table 4. Water quality values (q_i), based on different parameter values [21].

q_i	EC (µS/cm)	Na^+ (meq/L)	HCO_3^- (meq/L)	Cl^- (meq/L)	SAR
85-100	200-750	2-3	1 - 1,5	< 4	< 3
60-85	750-1500	3-6	1,5 – 4,5	4 - 7	3 - 6
35-60	1500-3000	6-9	4,5 – 8,5	7 - 10	6 - 12
0-35 0-35	< 200 > 3000	< 2 > 9	< 1 > 8,5	>10	>12

IWQI values for groundwater samples ranged from 25.49 to 87.03, with a mean of 69.47. Consequently, 21.96% of the samples were categorized as highly restrictive, 16.46% as moderately restrictive, 60.36% as falling within the low restrictive category, and 1.22% were classified as 'no restrictions' within the research area.

5 Conclusion

The present study examined the chemical composition of 164 water points in the Ketama region. Analysis using the Piper diagram revealed that the calcium bicarbonate chemical facies were predominant, constituting 80.34% of the samples. Various indicators were employed to assess irrigation water quality, including the PI, KR, PS, Ka, Cl, EC,% Na, SAR, RCS, MAR, Ka, K, and IWQI. Results from the irrigation water quality index indicated that the majority of samples exhibited outstanding to good irrigation quality. This study holds significant importance as it offers a comprehensive analysis of the chemical compositions of groundwater samples in the Ketama region. Furthermore, by evaluating irrigation water quality using multiple indices, the research contributes significantly to the sustainable management of water resources.

The prevalence of samples with excellent to good quality for irrigation emphasizes the vital role of these resources in the local agricultural context. This article thus makes an essential contribution to scientific knowledge and decision-making on water resource management in the Ketama region.

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